May 9, 1967 H. L. SMITH, JR 3,318,017

HEAT TREATING METHOD AND APPARATUS

Original Filed Jan. 29, 1963 2 Sheets-Sheet 1

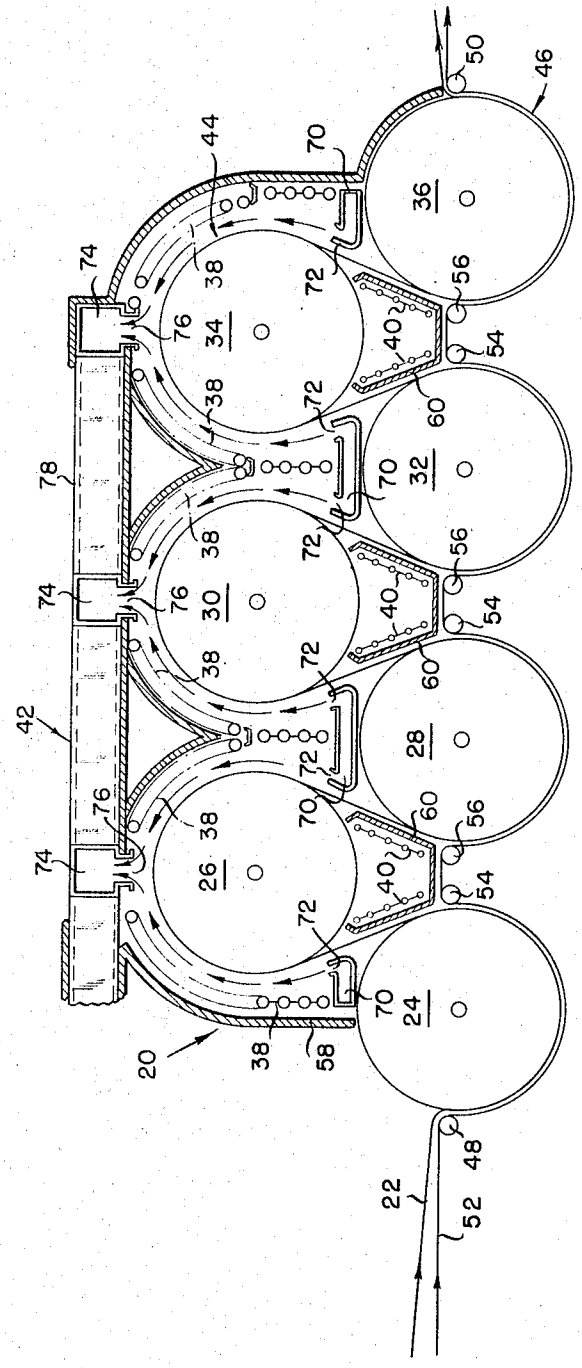


FIG. 1

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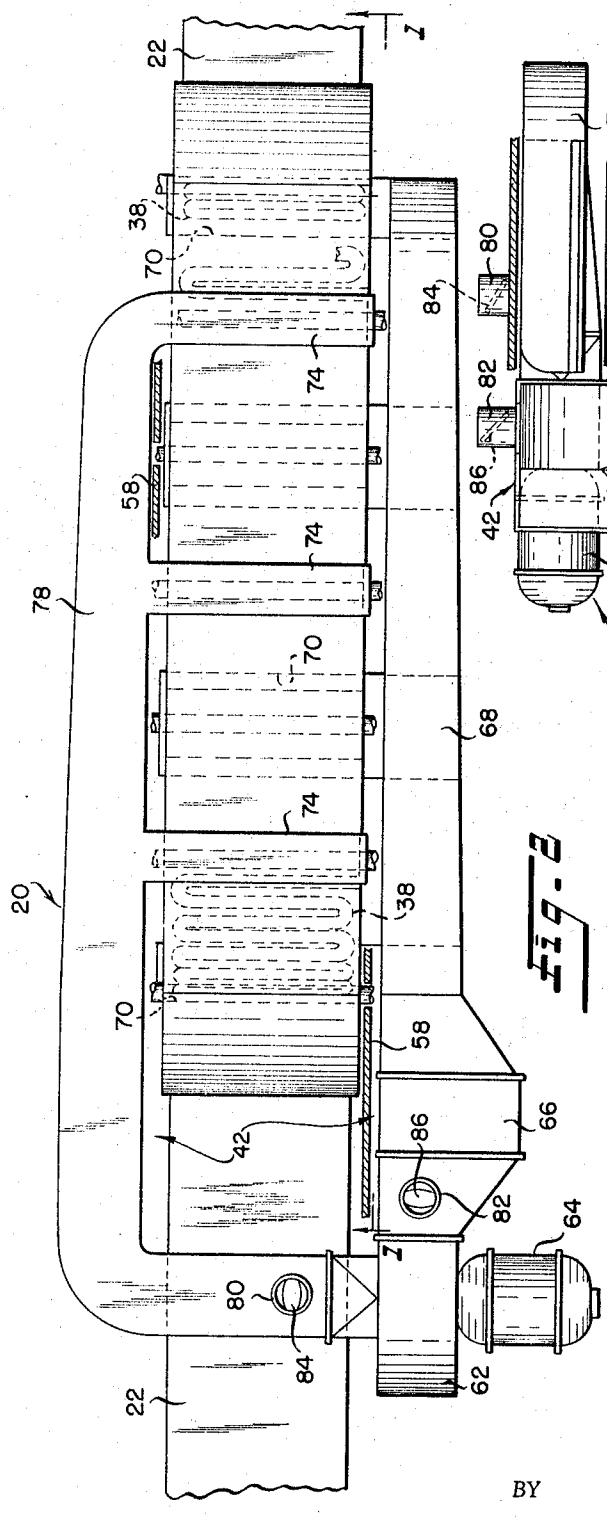


FIG. 2

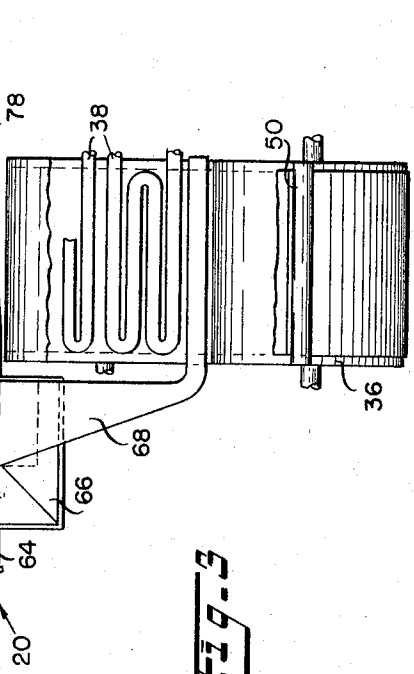


FIG. 3

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3,318,017

HEAT TREATING METHOD AND APPARATUS

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Continuation of application Ser. No. 254,674, Jan. 29, 1963. This application May 2, 1966, Ser. No. 547,128
6 Claims. (Cl. 34—114)

This application is a continuation of application No. 254,674, filed January 29, 1963, which is now abandoned.

This invention relates to the heat treatment of webs and continuous sheets of material, and, more particularly, to the drying of continuous webs of materials such as paper, plastic films, and the like. For convenience, the principles of this invention will be developed by relating them to paper drying. It is to be understood, however, that the principles of this invention may equally well be applied to the drying or heat treating of other, diverse types of web or continuous sheet materials including but not limited to those mentioned above. The term "sheet" will be hereinafter used to include continuous sheets, webs and similar forms of materials.

Continuous paper sheets are largely conventionally dried by passing them over serially arranged steam heated drying rolls, alternate ones of which are vertically displaced so that the drums are arranged in two vertically spaced decks. In the normal arrangement in such equipment the paper passes under one roll and over the next one so that heat is transferred by conduction from adjacent drying rolls to opposite sides of the paper to insure equal drying and thereby prevent curling. Such conventional drying systems have several disadvantages, particularly when operated at high speeds. As the paper passes over successive rolls, substantial portions of both faces of the sheet are in direct contact with the drying rolls. Moisture at and near the surface of the portions of the faces contacting the drying rolls is vaporized but cannot escape directly to the atmosphere because of the physical obstruction of the heating roll. As a result, the vapor pressure at the roll contacting face of the sheet increases, causing the water molecules to migrate toward the opposite exposed face of the sheet. Some of the water vapor will escape from the sheet through the exposed face; but, because the exposed face is relatively cool, many of the water molecules migrating toward the exposed face will condense and remain in the sheet, retarding the drying process.

Escape of water vapor from the drying sheet is further retarded in such conventional equipment by felt or similar belts looped around the drying rolls and covering the sheet to minimize wrinkles in the sheet and to increase the heat transfer rate between the drying rolls and the sheet by pressing the sheet against the drying rolls. Little if any moisture is absorbed by or penetrates and escapes from these belts.

In the preferred embodiment of the present invention, a felt belt is used to press the sheet into contact only with selected drying rolls (preferably those in the lower deck) to prevent wrinkles and to obtain maximum conductive heating. By not employing the belt around the drying rolls in the upper deck, large areas of the sheet are always exposed to the ambient atmosphere, substantially increasing the ease with which moisture may escape from the sheet. In addition, in the present invention, radiant heaters are preferably located closely adjacent the exposed surfaces of the sheet and heated air is blown between the radiant heaters and the sheet to more rapidly dry it and to sweep away moisture evaporating from it. It has been found that this combination of radiant, conductive, and convective heating results in an

unexpectedly large and surprising increase in drying efficiency in comparison to conventional equipment, permitting papermaking equipment to be run at increased speeds varying from 125 f.p.m. (paperboard) to 3000 or more f.p.m. (newsprint).

In the preferred embodiment of this invention, the heated air is directed between the paper and the radiating surfaces by nozzles equal in length to and extending across the width of the sheet. Air flow through the nozzles is preferably maintained at velocities of 1000 to 1500 f.p.m. relative to the velocity of the sheet being treated to cause turbulent flow in the zone between the moving sheet and the radiators as turbulent flow is substantially more effective in sweeping away evolved moisture than laminar flow. The combination of turbulent heated air moving at relatively high velocity over the sheet surface and the simultaneous application of radiant heat to the exposed surface of the sheet has a synergistic effect on the removal of moisture from the sheet, raising the drying rates of apparatus employing this combination of heat transfer mechanisms well beyond that which would be expected from a consideration of their additive effects.

The most pertinent prior art of which I am aware is my own British Patent 779,326 which discloses drying apparatus in which air is blown between the tops of rolls carrying wet web material and curved radiators for the sole purpose of eliminating vapor locks between the rolls and the radiators. Optimum air stream temperatures for vapor lock removal range from 100 to 150° F. and the air flow is preferably laminar. Laminar air flow retards heat transfer from a relatively low temperature air stream; contributes little, if anything, to the drying action of the apparatus other than vapor removal; and, in fact, may cause substantial re-entry of water molecules into the sheet, reducing drying efficiency.

In the present invention the radiators employed to add radiant heat to the sheet are preferably maintained at a temperature of 550° F. or higher, and the drying air is introduced through the nozzles at temperatures preferably in the order of 250° F. to 500° F. and at velocities on the order of 1000 to 1500 f.p.m. relative to the velocity of the sheet to evaporate water from the sheet and to sweep the emerging water vapor away from its surface. By employing drying air and radiant heat having these temperatures and velocity parameters, the present invention achieves wholly unexpected and surprising increases in drying efficiencies, efficiencies which would be impossible to obtain using my British patent disclosure.

Another advantage of my novel drying method and apparatus described above is that the addition of convection and radiant heating minimizes the non-uniformity in drying caused by variations in the thickness of the sheet. Consequently, the formation of puckers is minimized, producing a sheet of higher quality.

From the foregoing, it will be apparent that one object of the present invention resides in the provision of improved methods and apparatus for drying continuous, moving sheets of material.

Another specific object of the present invention resides in the provision of improved plural roll sheet drying apparatus having a substantially higher capacity than heretofore available apparatus of this type.

It is another specific object of the present invention to provide novel paper drying methods and apparatus which will minimize wrinkling and puckering of the paper.

Another object of the present invention resides in the provision of novel apparatus for drying continuous, moving sheets of material in which heat is transferred to the sheet by radiation and in which a stream of air

is directed across the surface of the moving sheet to remove from adjacent the sheet moisture evolved from it.

It is yet another object of the present invention to provide novel plural roll apparatus for drying continuous, moving sheets of material including means for transferring heat to the material at a rate entirely independent of the tension on the material.

Still another specific object of the present invention resides in the provision of novel apparatus for drying continuous, moving sheets of material by radiation and conduction in which the heat input to the opposite sides of the material is correlated to prevent it from curling.

It is yet another specific object of the present invention to provide improved multi-roll apparatus for drying continuous, moving sheets of paper in which, to a significant extent, the moisture trapping felt belts heretofore employed to prevent the paper from wrinkling are eliminated.

Other objects and advantages of the present invention will become apparent from the following description of the preferred mode of carrying out the present invention, and examples thereof, and from the appended claims and accompanying drawings wherein:

FIGURE 1 is a partially diagrammatic front elevation, partly in section, of a drying apparatus embodying the principles of the present invention;

FIGURE 2 is a plan view of the apparatus illustrated in FIGURE 1; and

FIGURE 3 is an end elevation view of the apparatus illustrated in FIGURE 1.

Referring now to the drawing, FIGURE 1 illustrates a drier **20** particularly adapted for drying a continuous, moving sheet of material **22**. Drier **20** includes, generally, a plurality of internally heated drying rolls **24–36** for heating sheet **22** by conduction, radiators **38** and **40** for applying radiant energy to sheet **22**, and a ventilating system **42** for heating sheet **22** by convection and for removing from adjacent sheet **22** vapors evolved from it by the heat applied to it by the heated air, the drying rolls, and the radiators.

Drying rolls **24–36** may be of any conventional construction, such as the steam heated rolls illustrated in my British patent, for example. They are arranged in two vertically spaced apart decks indicated generally by reference characters **44** and **46** with the rolls **26**, **30**, and **34** in upper deck **44** located approximately midway between the drying rolls in lower deck **46**. As shown in FIGURE 1, sheet **22** is guided onto the first drying roll **24** by a guide roller **48** and then moves around drying rolls **26**, **28**, **30**, **32**, **34**, and **36** in that order, alternately passing between rolls in upper deck **44** and lower deck **46**. Sheet **22** is guided from the last drying roll **36** by a guide roller **50**.

A felt belt **52** is employed to press sheet **22** into contact with the drying rolls **24**, **28**, **32**, and **36** in lower deck **46** to provide optimum conduction of heat from the drying rolls to sheet **22** and to prevent the formation of wrinkles in the sheet. Felt belt **52** is guided around the drying rolls in lower deck **46** by the guide rollers **48** and **50** discussed above and by pairs of guide rollers **54** and **56** located between adjacent rolls in the lower deck **46**. Felt belt **52** is maintained under high tension in any suitable manner so that it will exert pressure in a direction normal to the sheet contacting surface portions of the drying rolls in lower deck **46**.

Except for the novel arrangement of felt belt **52**, that portion of applicant's novel drier **20** described above is similar to the conventional multi-roll drier commonly employed in the drying of paper. In a common method of manufacture of paper (and by the term paper is meant diverse products such as newsprint, paperboard, and the like), a mixture of water and fiber is continuously delivered onto a closely woven wire Fourdrinier conveyor. The water drains through the conveyor, forming a continuous mat of fibers on its upper side. After additional moisture is removed from the mat thus formed, as by suction boxes, the mat is passed through a multi-roll drier to complete the drying process.

As far as practicable, the rate at which the furnish or stock (typically consisting of 1–2% fiber and 98–99% water) flows onto the conveyor is maintained constant so that the thickness of the sheet will be uniform. In actual practice of such prior methods it is impossible to achieve a high degree of uniformity and, as a result, what are known as "wet streaks" are present in the sheet when it reaches the multi-roll drier. The presence of wet streaks is undesirable since they dry more slowly than the remainder of the sheet which, as a result, shrinks to a greater extent than the wet streaks. Consequently, the wet streaks are not held tightly against the drying rolls and, therefore, tend to pucker or expand, lowering the quality of the finished product. The conventional multi-roll drier tends to aggravate the formation of puckers and wrinkles since the drying sheet is heated solely by conduction and the rate at which the drying rolls conduct heat to the sheet is dependent upon the tension of the sheet. Thus, in the conventional multi-roll drier, the "dry streaks" (the areas other than wet streaks) are the only portions of the sheet under tension and, therefore, dry at a faster rate than the wet streaks throughout the entire pass through the drier.

It is one of the novel features of the present invention that, notwithstanding the presence of wet streaks in the sheet entering drier **20**, non-uniform drying of the sheet is minimized and substantially eliminated. This is effected by utilizing, in addition to steam heated drying rolls **24–36**, heat transfer which is independent of the tension on sheet **22** and which adds heat to the wet streaks at a faster rate than to the dry streaks. The rate at which heat is transferred to a sheet of material by radiation or by convection is independent of the tension on the sheet and the novel drier **20** of the present invention employs both of these heat transfer mechanisms to provide substantially uniform drying of sheet **22**.

Radiant energy is applied to sheet **22** by the radiators **38** and **40** referred to above. Radiators **38** and **40** may be of any desired construction; for example, that disclosed in copending application No. 64,965, filed October 25, 1960, by Horace L. Smith, Jr., for Paper Drying System, Apparatus and Method (now Patent No. 3,174,228). As is best shown in FIGURE 1, two radiators **38** are employed in association with each of the drying rolls **26**, **30**, and **34** in upper deck **44**. The two radiators **38** employed with each of these rolls subtend substantially that portion of the associated drying roll contacted by the sheet of material **22** being dried; i.e., somewhat more than half of the roll surface. Radiators **38** are supported in any desired manner closely adjacent the surfaces of the associated drying rolls, the distance between the radiators and the drying rolls preferably being the minimum needed to permit sheet **22** to be readily threaded around the drying rolls. Radiators **38** are surrounded by suitable reflectors indicated generally by reference character **58** so that the maximum portion of radiant energy emitted from the radiators will be directed onto sheet **22**.

Two radiators **40** are mounted in any desired manner subjacent each of the drying rolls **26**, **30**, and **34** in upper deck **44**. Radiators **40** are separated from sheet **22** as it passes between the upper and lower decks of drying rolls **44** and **46** by guides **60** to prevent broke from contacting the radiators.

Radiators **38** and **40** are preferably maintained at a temperature on the order of 550° F. or higher by circulating through them a high boiling point organic liquid such as Aroclor 1248, a biphenyl manufactured by Monsanto Chemical Co. A preferred system for heating and circulating the heat transfer liquid is disclosed in copending application No. 237,817, filed November 15, 1962, by Horace L. Smith, Jr., for High Temperature Heating Appa-

ratus (now Patent No. 3,236,292), to which reference may be had if deemed necessary.

At a temperature of 550° F. radiators **38** and **40**, the emitting surfaces of which have an emissivity coefficient of about 0.95, emit approximately 1,300 B.t.u.'s of radiant energy per square foot per hour. As it requires approximately 1,000 B.t.u.'s to evaporate one pound of water, each square foot of the radiators **38** and **40** will emit sufficient energy to evaporate approximately 1.3 pounds of water per hour from sheet **22**. Therefore, in addition to promoting more uniform drying, radiators **38** and **40** evaporate substantial quantities of water from sheet **22**, permitting the velocity of sheet **22** through the drier to be materially increased or, alternatively, permitting the number of drying rolls to be decreased. In either case the capacity of a drier constructed in accordance with the present invention is substantially increased over that of a conventional multi-roll drier of equal size.

Preferably, as in the illustrated embodiment, radiant energy is applied to both sides of sheet **22** to equalize the heat input and thereby prevent the curling which would occur if the opposite sides of the sheet were unequally heated.

In the drying of continuous, moving sheets of material in multi-roll driers, the heat applied to the material by the drying rolls causes molecules of the liquid in the material to evaporate from the surfaces of the material which are not in contact with a drying roll or a felt and are therefore free or exposed. This forms a dry boundary layer in the material and a vaporous barrier layer adjacent its exposed surfaces. As the drying process continues, molecules of the liquid in the material migrate from the material through the dry boundary layer and escape from the material into the barrier layer. As the concentration of molecules in the barrier layer increases, these molecules diffuse toward areas of lower concentration. Since the dry boundary layer of the material is immediately adjacent the barrier layer, some of the diffusing molecules will return to the material, retarding the drying process. To remove the liquid from the barrier layer and hasten the drying process by preventing the molecules in this layer from returning to the boundary layer, the ventilating system identified by reference character **42** is employed.

As is best shown in FIGURE 2, ventilating system **42** includes a blower **62** driven by a motor **64** which directs air through a suitable air heater **66** such as that shown in copending application No. 271,801 filed April 9, 1963 by Horace L. Smith, Jr., for Dryers (now Patent No. 3,208,158), where the air is heated to a temperature above the boiling point of the liquid being evaporated from sheet **22** and below the temperature of radiators **38** and **40**. For paper drying the air is preferably heated to a temperature in the range of 250–500° F. From heater **66**, the air passes into an inlet air manifold **68** which conveys the hot air downwardly into a plurality of plenums **70** (FIGURE 1) from which the air is discharged through nozzles **72** as shown by the arrows in FIGURE 1 between the drying rolls **26**, **30**, and **34** in upper deck **44** and the radiators **38** surrounding these rolls, preferably at a velocity in the range of 1000–1500 feet per minute greater than the speed at which the web is moving. In relation to the movement of the paper, part of the air flow is concurrent and part countercurrent; and, consequently, the relative velocity between the air stream and sheet **22** will be different on opposite sides of nozzles **72** at each drum as the air will be flowing in the direction of web movement on one side of each nozzle and opposite to the direction of web movement on the other side of the nozzle. Nozzles **72** are preferably at least as long as the width of sheet **22** so that the heated air will be distributed across its entire surface.

The heated air flows upwardly between the radiators and sheet **22**, through outlet plenums **74** (which have inlets **76** located between the two radiators **38** associated with each of the drying rolls in upper deck **44**), and into outlet manifold **78** which recirculates the air to blower **62**.

The heated air sweeps across sheet **22** as it travels over the drying rolls **26**, **30**, and **34** in upper deck **44**, carrying away the vapor in the barrier layer adjacent its surface and thereby preventing the molecules in the barrier layer from returning to sheet **22** as they would otherwise do. In addition, the heated air heats sheet **22** by convection, further hastening the drying process by increasing the rate at which vapor is evolved from sheet **22** and increasing the capacity of drier **20** over that of a conventional multi-roll drier of comparable size.

At the velocities and temperatures described above, the flow of the heated air stream between radiators **38** and the associated rolls in upper deck **44** is highly turbulent, the flow condition most effective in removing evolved vapors from adjacent sheet **22** and in transferring heat to it by convection. Preferably, the turbulence of the flowing air is increased by providing the inner surfaces of radiators **38** with undulating or transversely rippled formations or by fixing spaced fins to these surfaces. To further increase the turbulence of the flowing air, a coarse mesh, open weave belt may be substituted for felt belt **52**.

As sheet **22** passes through drier **20**, it reaches a stage of dryness corresponding approximately to the condition of fiber saturation in which the free water between the fibers has been evaporated. At this point, which is termed the "falling rate" portion of the drying cycle, the drying rate begins to decrease. The dry streaks reach the falling rate part of the drying cycle considerably sooner than the wet streaks and, after reaching this stage, dry at a substantially lower rate than the wet streaks which therefore continue to absorb heat from radiators **38** and from the heated air circulated between the radiators and the sheet at a maximum rate. As a result, the dry streaks dry slowly and the wet streaks dry considerably more rapidly and the sheet as a whole dries at a substantially more uniform rate than has heretofore been possible, minimizing the formation of wrinkles and puckers in the sheet.

Adjacent the outlet end of drier **20**, where sheet **22** approaches a substantially dry state, the temperature of radiators **38** and the temperature of the heated air discharged through nozzles **72** may be decreased to lower the rate at which heat is transferred to sheet **22** to protect it from overheating.

Escape of the evolved vapor from the sheet in a conventional multi-roll drier is inhibited by the fact that felt belts are employed to press the sheet against the drying rollers in the upper deck as well as in the lower deck, an arrangement which has heretofore been thought to be necessary to prevent wrinkles in the paper. As a result, the major portions of both sides of the sheet are either covered by the felt belt or in contact with the drying rollers; and, as a result, there is only limited area exposed surface through which the evaporated liquid may escape from the sheet.

In the present invention, in contrast, removal of moisture from sheet **22** is enhanced by the fact that sheet **22** is not covered with a felt belt as it passes over the rollers **26**, **30**, and **34** in upper deck **44**. This provides considerably more exposed surface from which the evaporated moisture may escape from the sheet than do the conventional prior art driers. Surprisingly, it has been found that the elimination of the felt belt from the upper deck rollers **26**, **30**, and **34** has substantially no adverse effect on preventing the formation of wrinkles and puckers in sheet **22**. Elimination of the felt belt around the upper deck rollers **26**, **30**, and **34**, in addition, makes it possible to advantageously employ radiant heaters in combination with a multi-roll type drier in contrast to the conventional arrangements heretofore employed in which such energy would, of course, be absorbed by the felt belts.

In most instances, it will be desirable to retain a small percentage of the liquid in the dried sheet **22**. For some types of paper, for example, the dried product should

have a moisture content on the order of 5%. In the novel drier **20** of the present invention, the moisture content of the dried sheet **22** may be accurately and easily controlled by regulating the relative humidity of the drying air discharged through nozzles **72**. For this purpose, an exhaust air duct **80** and a make-up air duct **82** are provided in exhaust manifold **78** and inlet manifold **68**, respectively. Flow through exhaust duct **80** and make-up air duct **82** is regulated by valves **84** and **86** disposed in ducts **80** and **82**, respectively. Valves **84** and **86** may be adjusted manually or may be automatically operated by the automatic humidity control system disclosed in copending application No. 271,801 filed April 9, 1963 by Horace L. Smith, Jr., for Dryers (now Patent No. 3,208,158).

The invention may be embodied in other specific forms without departing from the spirit or essential characteristics thereof. The present embodiment is therefore to be considered in all respects as illustrative and not restrictive, the scope of the invention being indicated by the appended claims rather than by the foregoing description, and all changes which come within the meaning and range of equivalency of the claims are therefore intended to be embraced therein.

What is claimed and desired to be secured by Letters Patent is:

1. Apparatus for heat treating a continuous, moving sheet of material, comprising:

(a) a plurality of substantially horizontally disposed drying rolls alternately located in first and second, vertically spaced apart decks and adapted to have a sheet of material contacting, respectively, their upper and lower surface portions, all of said rolls being internally heated;

(b) belt means for holding said sheet material against the rolls in one of said decks only, the other of said decks being entirely free of such belt means to permit volatiles evolved from the material being dried to escape freely from adjacent the surface of said material; and

(c) radiant heater means for applying radiant energy directly to the exposed surface of said sheet only in the deck which is free of belt means so that said radiant energy is transferred with maximum efficiency from said heater means to said material;

(d) whereby there are drying rolls free of said belt means and with external heater means therearound to transfer radiant energy from said heater means to said material in sufficiently large amounts to significantly increase the rate at which said material is dried and yet belt means pressing said material against a sufficient number of drying rolls to prevent the formation of wrinkles in said material and to insure a heat conductive relationship between the material and the drying rolls.

2. Apparatus for heat treating a continuous, moving, sheet of material, comprising:

(a) a plurality of substantially horizontally disposed drying rolls alternately located in first and second vertically spaced apart decks, all of said rolls being internally heated;

(b) belt means for holding said sheet material against the rolls in one of said decks, the other of said decks being entirely free of such belt means to permit volatiles evolved from the material being dried to escape freely from adjacent the surface of said material;

(c) radiant heater means around the internally heated drying rolls only in the other of said decks which is free of belt means for applying radiant energy directly to the exposed surface of said sheet in said other deck so that said radiant energy is transferred with maximum efficiency from said heater means to said material;

(d) whereby there are drying rolls free of said belt means and with external heater means therearound to transfer radiant energy from said heater means to said material in sufficiently large amounts to significantly increase the rate at which said material is dried and yet belt means pressing said material against a sufficient number of drying rolls to prevent the formation of wrinkles in said material and to insure a heat conductive relationship between the material and the drying rolls;

(e) air supply means for introducing streams of air between the radiant heater means and the drying rolls of said other deck at a velocity sufficiently high to remove from adjacent said sheet vapors evolved therefrom, said air supply means being associated only with the rolls of said other deck, and said air supply means including a plurality of inlet plenums located adjacent and spanning the length of the drying rolls in said other deck, means forming in each plenum at least one nozzle communicating with the interior of the plenum and having an outlet closely adjacent one of said drying rolls; and

(f) means for exhausting the vapor laden air streams from between said sheet material and said radiant heater means.

3. Apparatus as defined in claim **2**, together with:

(a) a supply manifold in fluid communication with said inlet plenums;

(b) an air heater with its outlet communicating with the interior of said manifold; and

(c) a blower with its outlet communicating with the inlet to the air heater to force air seriatim through the air heater and the inlet manifold, into the inlet plenums, and through the nozzles communicating therewith.

4. Apparatus as defined in claim **3**:

(a) wherein said exhaust means comprises exhaust plenums above and spanning each of the drying rolls in said other deck, said plenums having inlet openings in the bottom thereof;

(b) an exhaust manifold in fluid communication with said exhaust plenums and the inlet of said blower, whereby said air supply means and said exhaust means constitute a closed system providing for recirculation of said air;

(c) an exhaust duct communicating with said closed system and open at one end to the atmosphere;

(d) a makeup air duct communicating with said closed system and open at one end to the atmosphere; and

(e) selectively adjustable valves in the exhaust and makeup air ducts for controlling the discharge of vapor laden air from and the entry of fresh air into said system.

5. Apparatus for heat treating a continuous, moving sheet of material, comprising:

(a) a plurality of substantially horizontally disposed drying rolls alternately located in first and second, vertically spaced apart decks and adapted to have a sheet of material contacting, respectively, their upper and lower surface portions;

(b) belt means for holding said sheet material against the rolls in one of said decks only, the other of said decks being free of felts;

(c) radiant heater means for applying radiant energy to the exposed surface of said sheet only in the other of said decks;

(d) means for introducing a stream of gas between said radiant heater means and the sheet material on the rolls in said other deck and directing said gas around said rolls adjacent said sheet material at a velocity sufficiently high to remove from adjacent said sheet vapor evolved therefrom; and

(e) means for exhausting the vapor laden gaseous stream from between said sheet material and said heater means;

(f) the means for introducing said stream of gas be-

tween said heater means and said sheet material comprising:

(g) means forming at least one plenum chamber located between adjacent rolls in said second deck; and

(h) means forming a pair of nozzles in said plenum chamber, said nozzles being in fluid communication with the interior of said chamber and each of said nozzles being directed toward the adjacent one of the drying rolls between which the associated plenum chamber is located, said nozzles having outlets closely adjacent and spanning the length of said drying rolls.

6. Apparatus for heat treating a continuous, moving sheet of material, comprising:

(a) a plurality of substantially horizontally disposed drying rolls, alternately located in first and second, vertically spaced apart decks and adapted to have a sheet of material contacting, respectively, their upper and lower surface portions, all of said rolls being internally heated;

(b) belt means for holding said sheet material against the rolls in one of said decks only, the other of said decks being entirely free of such belt means to permit volatiles evolved from the material being dried to escape freely from adjacent the surface of said material;

(c) radiant heater means for applying radiant energy directly to the exposed surface of said sheet only in the deck which is free of belt means so that said radiant energy is transferred with maximum efficiency from said heaters to said material;

(d) whereby there are drying rolls free of said belt means and with external heater means therearound

to transfer radiant energy from said heater means to said material in sufficiently large amounts to significantly increase the rate at which said material is dried and yet belt means pressing said material against a sufficient number of drying rolls to prevent the formation of wrinkles in said material and to insure a heat conductive relationship between the material and the drying rolls;

(e) means for introducing a stream of gas between said radiant heater means and the sheet material on the rolls only in the deck which is free of belt means and for directing said gas around said rolls adjacent said sheet material at a velocity sufficiently high to remove from adjacent said sheet vapor evolved therefrom; and

(f) means for exhausting the vapor laden gaseous stream from between said sheet material and said radiant heater means.

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